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RESEARCH MEMORANDUM

SOME EFFECTS OF BLADE TRAILING-EDGE THICKNESS ON
PERFORMANCE OF A SINGLE-STAGE AXIAL-FLOW
COMPRESSOR

By J. J. Moses and G. K. Serovy

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

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RESEARCH MEMORANDUM

SOME EFFECTS OF BLADE TRAILING-EDGE THICKNESS ON PERFORMANCE

OF A SINGLE-STAGE AXIAL-FLOW COMPRESSOR

By J. J. Moses and G. K. Serovy

SUMMARY

An investigation was conducted to determine some effects of blade trailing-edge thickness on the performance of a single-stage axial-flow compressor having a tip diameter of 14 inches and a hub-to-tip diameter ratio of 0.8 at the rotor leading edge. A rotor row of modified NACA 65-series blower blades designed for high inlet Mach numbers, high blade loading, and axial inlet velocity was investigated for blade trailing-edge thicknesses of 0.045, 0.030 and 0.015 inch, which gave ratios of trailing-edge thickness to maximum blade thickness of 0.30, 0.20, and 0.10. Over-all total-pressure ratio and adiabatic efficiency were determined for a complete range of weight flows at six equivalent tip speeds from 450 to 915 feet per second. A range of relative equivalent inlet Mach number from 0.40 to 0.93 at the rotor mean radius was covered; the approximate Reynolds number based on blade chord varied from 261,000 to 604,000.

No measurable effect of trailing-edge thickness on total-pressure ratio was obtained over the efficient operating speed range of the compressor. The efficiency tended to increase slightly with increasing trailing-edge thickness. The magnitude of the change, however, was within the accuracy of measurement (1 to 2 percent). A lower critical Mach number was indicated for the 0.015-inch thickness than for the 0.030- and 0.045-inch thicknesses.

Trailing-edge thicknesses up to 30 percent of maximum blade thickness were used without sacrifice of performance for the NACA 65-series blade sections.

INTRODUCTION

Axial-flow compressor-blade fabrication would be simplified if the permissible thickness of the blade trailing edge could be increased over the theoretically determined blade profile. Increasing the blade trailing-edge thickness may introduce a decrease in blade operating

efficiency. The data of references 1 to 3 indicate that to obtain maximum blade-section efficiency, the thickness of the trailing edge should be as small as possible. On the other hand, no appreciable trailing-edge-thickness effect on blade performance for thicknesses up to 20 percent of the maximum blade thickness is indicated in reference 4.

Results for isolated airfoils presented in reference 5 show that an increase in lift and an increase in profile losses occur when trailing-edge thickness is increased. If the lift increases, a decrease in blade-section lift-drag ratio will not necessarily result in a decrease in compressor efficiency because blade-profile losses are only a small part of the total losses of a compressor. Therefore the investigation was conducted to determine the effect of blade trailing-edge thickness on the performance of a typical axial-flow compressor stage.

A single row of compressor blades with modified NACA blower blade sections of 65-(14)10, 65-(9.6)09, and 65-(7.3)08 at the hub, mean, and tip radius, respectively, was installed in a 14-inch diameter single-stage compressor test rig. The performance of this blade row was compared over a range of flows at six equivalent tip speeds from 450 to 915 feet per second for trailing-edge thicknesses of 0.045, 0.030, and 0.015 inch.

As a check on the results obtained from the compressor tests, a brief supplementary investigation was made on a two-dimensional cascade of NACA 65-(12)10 blades with trailing-edge thicknesses of 0.045 and 0.010 inch.

SYMBOLS

The following symbols are used in this report:

P	absolute total pressure, (lb/sq ft)
r	radius to blade element, (ft)
U_t	blade-tip velocity, (ft/sec)
$U_t/\sqrt{\theta}$	equivalent tip speed, (ft/sec)
W	weight flow, (lb/sec)
$W\sqrt{\theta}/\delta$	weight flow corrected to NACA standard sea-level conditions, (lb/sec)

δ ratio of inlet total pressure to standard sea-level pressure

η_{ad} adiabatic efficiency

θ ratio of inlet total temperature to standard sea-level temperature

Subscripts:

0 depression tank

2 outlet measuring station

t tip

APPARATUS

Compressor Blading and Design

The blading used for this investigation was similar to that of reference 6 with the exception of the modified trailing-edge and consisted of a single row of 29 rotor blades designed for axial inlet velocity and having a constant solidity of 1.2. Modified NACA 65-(14)10, 65-(9.6)09, and 65-(7.3)08 blower-blade sections were used at hub, mean, and tip sections, respectively. Chord length varied from 1.460 at the hub to 1.641 at the mean radius and 1.822 inches at the tip. The blades were fabricated with a trailing-edge thickness of 0.045 inch, which was then reduced by hand-finishing to 0.030 and 0.015 inch, successively. The ratio of blade trailing-edge thickness to maximum blade thickness is approximately 0.10, 0.20, and 0.30 for the 0.015-, 0.030-, and 0.045-inch thicknesses.

The trailing-edge thickness was increased equally on the suction and pressure surfaces. The theoretical airfoil was first designed with zero camber (fig. 1(a)) and lines were drawn from the extremities of the desired trailing-edge tangent to the blade surfaces. The new thickness distribution was then placed on the cambered airfoil (fig. 1(b)). This procedure eliminated the point of inflection that exists on the aft portion of the theoretical airfoil.

The blading was installed in a variable-component axial-flow compressor having a constant tip diameter of 14 inches and hub-to-tip diameter ratio of 0.8 at the rotor inlet. Static rotor tip clearance was approximately 0.020 inch.

Compressor Installation and Instrumentation

The compressor installation is shown schematically in figure 2 and is similar to that described in reference 6. Instrumentation for determination of over-all compressor performance was similar to that of reference 6 and was located at the stations indicated in figure 2.

Cascade Installation and Blading

The cascade studies were made on a $3\frac{1}{2}$ -inch two-dimensional, solid-wall cascade. A set of six NACA 65-(12)10 blades having a chord length of 1.5 inches, a solidity of 1.0, and a stagger angle of 45° was installed in the cascade and tested for trailing-edge thicknesses of 0.010 and 0.045 inch. The blades were altered to obtain the desired trailing-edge thickness in the same manner as the compressor blades.

PROCEDURE AND METHOD OF CALCULATION

For each trailing-edge thickness, compressor performance was measured at equivalent tip speeds of 450, 600, 736, 798, 874, and 915 feet per second. At each speed, the weight flow was varied from an approximate maximum to the region of unstable operation. A constant pressure of 25 inches of mercury absolute was maintained in the depression tank for all speeds and weight flows. The range of equivalent relative inlet Mach numbers and Reynolds numbers covered at each tip speed is summarized in table I.

The methods of reference 6 were used to calculate the total-pressure ratio and the adiabatic efficiency of the compressor. Over-all total-pressure ratio was obtained from a mass-flow-weighted average of the isentropic energy input integrated across the flow passage. The adiabatic efficiency was obtained by dividing the integrated isentropic energy input to the air by the integrated energy input due to change in angular momentum across the rotor.

RESULTS AND DISCUSSION

A comparison of blade-row performance for three blade trailing-edge thicknesses at each of six equivalent tip speeds is shown in figure 3. The curves shown were drawn through the data for the 0.015-inch trailing-edge thickness. Over the efficient operating range of the compressor, that is, tip speeds up to 874 feet per second, no appreciable effect of trailing-edge thickness on total-pressure ratio was measured. The compressor efficiency, however, tended to increase with

increasing trailing-edge thickness. Although the differences (about 1 to 2 percent) were within the accuracy of measurement, they were consistent for the speeds investigated. At an equivalent tip speed of 915 feet per second (relative inlet Mach number of about 0.9), an appreciable drop in efficiency occurred, which indicated shock losses. Although little change in total-pressure ratio or efficiency occurred between the 0.045- and 0.030-inch thicknesses, a noticeable decrease in both total-pressure ratio and efficiency took place for the 0.015-inch thickness, which indicated a lower critical Mach number.

A comparison of these results with those of reference 6 indicates that trailing-edge thickness has less effect over the range investigated on the performance of a blade row than do other small variations in blade row geometry. Although care was exercised to maintain a constant blade angle throughout the investigation, a reasonable tolerance in blade angle was allowed for the initial setting of the blades. The blade settings for this investigation were probably different from those of reference 6 and therefore, although the peak efficiency and pressure ratios were comparable (fig. 3), the weight flows at which these peak values occurred were different because of the blade setting.

In figure 4 a comparison is made of the radial variation of total-pressure ratio and adiabatic efficiency for the three thicknesses investigated. The curves are plotted for a point in the useful operating range of the compressor corresponding to a relative equivalent inlet Mach number of approximately 0.7 and for a corrected weight flow of 11 pounds per second on the curves of figure 3(c). Except near the hub and the tip where flow conditions are poor, the trailing-edge-thickness effect was negligible even though the chord length and blade section vary from hub to tip. At higher speeds where a noticeable trailing-edge thickness effect occurs the effect, in general, was the same at all radii.

A rough check on the compressor results with the two-dimensional cascade indicated an increase in lift of about 8 percent when the blade trailing-edge thickness was increased from 0.010 to 0.045 inch. Wake surveys, however, indicated a sufficient broadening of the wake to cause a decrease in lift-drag ratio of approximately 4 percent. The increase in lift is in agreement with the results obtained in reference 5, which ascribes the increased lift characteristics for increasing trailing-edge thickness to the decreasing magnitude and extent of adverse pressure gradient over the trailing edge of the airfoil.

The increase in lift caused by the thicker trailing edge could result in an increase in compressor efficiency even with a decrease in lift-drag ratio because the drag measured in a cascade includes only the profile losses, which are a small part of the total losses in a compressor. In the compressor tests, however, no appreciable increase in lift or energy addition was observed with increasing trailing-edge thickness. The basis of this discrepancy between the cascade and the

compressor results is not evident, but may be the result of the secondary flows and the effect of rotating-blade wakes on the flow measurements in the compressor.

The compressor results show that trailing-edge thicknesses up to 30 percent of maximum blade thickness can be used without appreciably affecting the performance of blade sections having loading distributions similar to that of the NACA 65-series airfoil sections.

SUMMARY OF RESULTS

An investigation was made to determine some effects of blade trailing-edge thickness on the performance of a single-stage axial-flow compressor using a rotor row of highly-loaded NACA 65-series blower blades designed for axial inlet velocity. Over-all compressor performance was compared for blade trailing-edge thicknesses of 0.045, 0.030, and 0.015 inch. The trailing-edge thickness varied from 30 to 10 percent of maximum blade thickness. A range of weight flows was covered at each of six equivalent tip speeds from 450 to 915 feet per second. The relative equivalent inlet Mach numbers varied from 0.40 to 0.93 and the approximate Reynolds numbers from 261,000 to 604,000. The results are summarized as follows:

1. Over the efficient operating speed range of the compressor (up to an equivalent tip speed of 874 ft/sec) no measurable effect on total pressure was obtained when the blade trailing-edge thickness was varied from 0.015 to 0.045 inch. The efficiency showed a tendency to increase slightly with increasing trailing-edge thickness. The magnitude, however, was within the accuracy of measurement (1 to 2 percent).

2. At an equivalent tip speed of 915 feet per second, little difference in total-pressure ratio and efficiency for the 0.045- and 0.030-inch thicknesses occurred. A noticeable decrease in performance for the 0.015-inch thickness indicated a lower critical Mach number for this trailing-edge thickness.

3. Trailing-edge thicknesses up to 30 percent of maximum blade thickness were used without sacrifice of performance for NACA 65-series blade sections.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCES

1. Reeman, J., and Simonis, E. A.: The Effect of Trailing Edge Thickness on Blade Loss. Tech. Note No. 116, British R.A.E., March 1943.
2. New, Winston R.: Dependence of Stage Efficiency upon the Trailing Edge Thickness of the Blades at Subacoustic Velocities. Rep. No. E. 1034, Order No. 6-51002-5 Westinghouse July 11, 1939.
3. Sargent, R. F.: Tests on NACA 0012 with Various Thick Trailing Edges at High Speeds. R. & M. No. 2209, British A.R.C., Nov. 1942.
4. Carter, A. D. S.: The Low Speed Performance of Related Aerofoils in Cascade. Rep. No. R 55, British N.G.T.E., Sept. 1949.
5. Summers, James L., and Page, William A.: Lift and Moment Characteristics at Subsonic Mach Numbers of Four 10-Percent-Thick Airfoil Sections of Varying Trailing-Edge Thickness. NACA RM A50J09, 1950.
6. Dugan, Paul D., Mahoney, John J., and Benser, William A.: Effect of Mach Number on Performance of an Axial-Flow-Compressor Rotor-Blade Row. NACA RM No. E8D29, 1948.

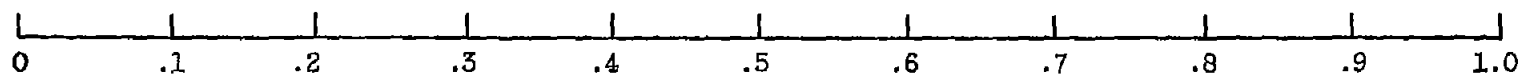
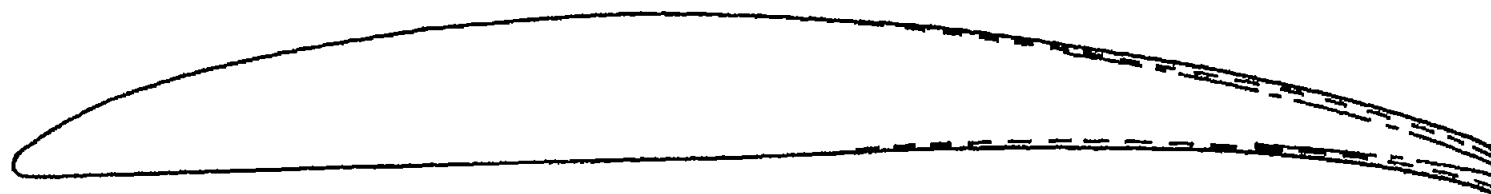
TABLE I - EQUIVALENT RELATIVE MACH NUMBER AND REYNOLDS
NUMBER AT ROTOR INLET

Equivalent tip speed (ft/sec)	Percent of design speed	Equivalent relative inlet Mach number		Reynolds number	
		Minimum	Maximum	Minimum	Maximum
450	61.1	0.40	0.52	2.61×10^5	3.56×10^5
600	81.5	.54	.66	3.59	4.46
736	100	.66	.78	4.37	5.20
798	108.4	.72	.84	5.05	5.52
874	118.7	.79	.90	5.34	5.88
915	124.3	.81	.93	5.71	6.04


 NACA



(a) Method of increasing trailing-edge thickness.



Distance along chord, fraction of chord

(b) Final airfoil shape.

Figure 1. - Airfoil profile at mean radius for three trailing-edge thicknesses.

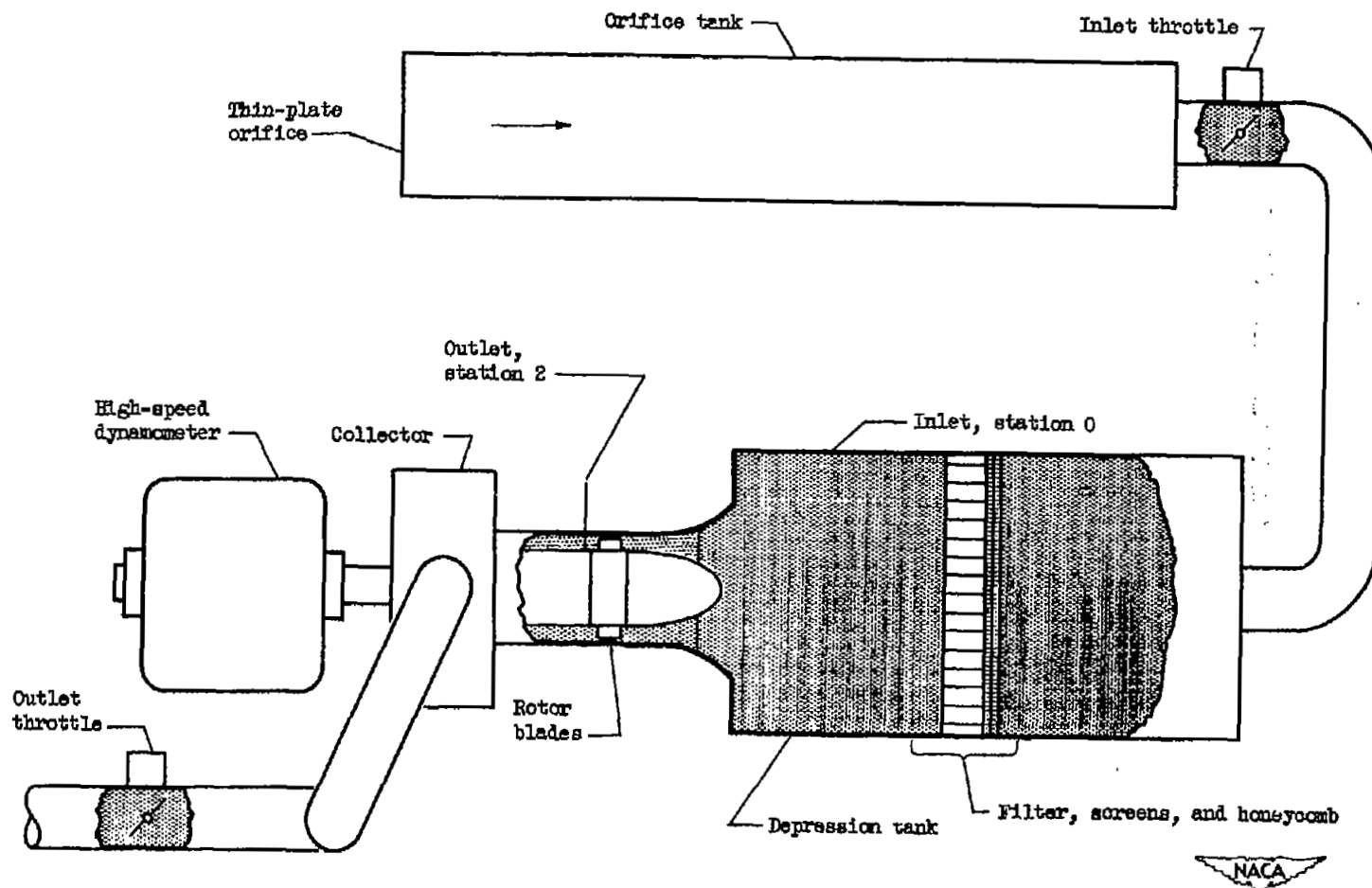


Figure 2. - Schematic diagram of compressor installation.

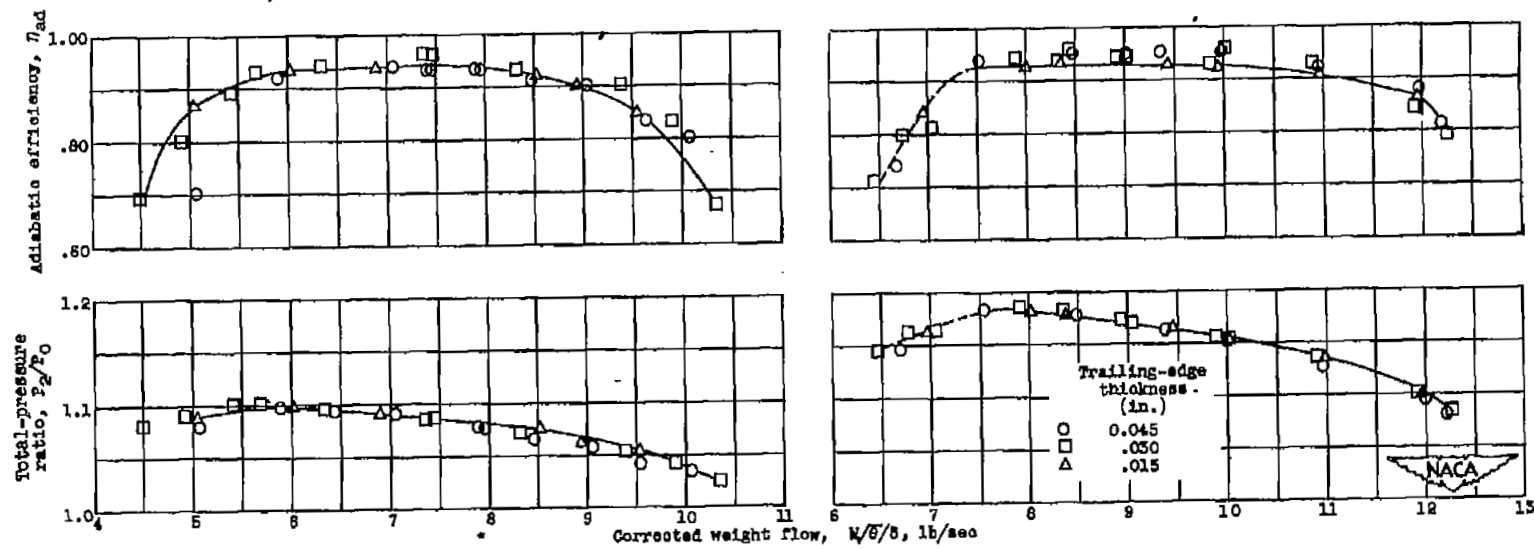
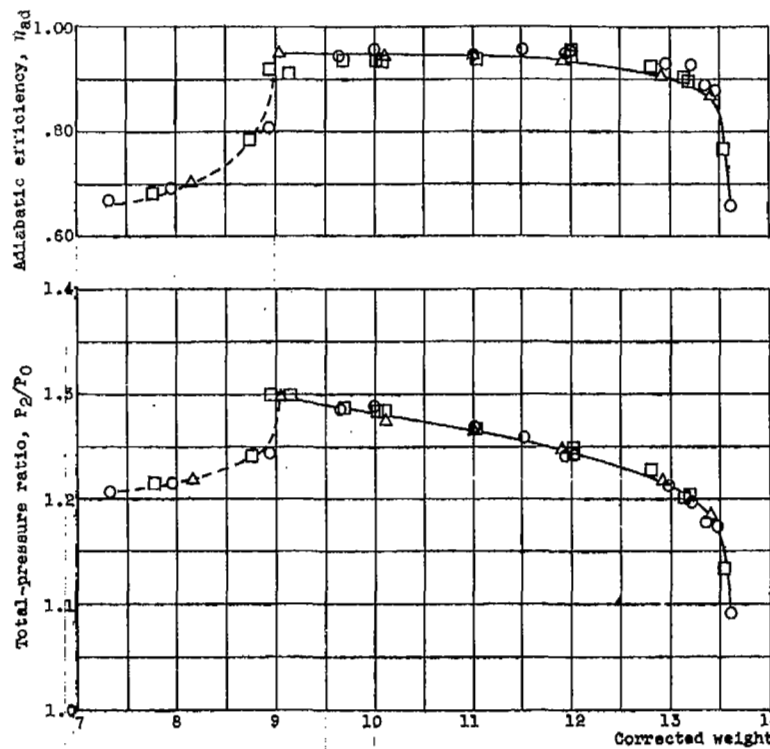
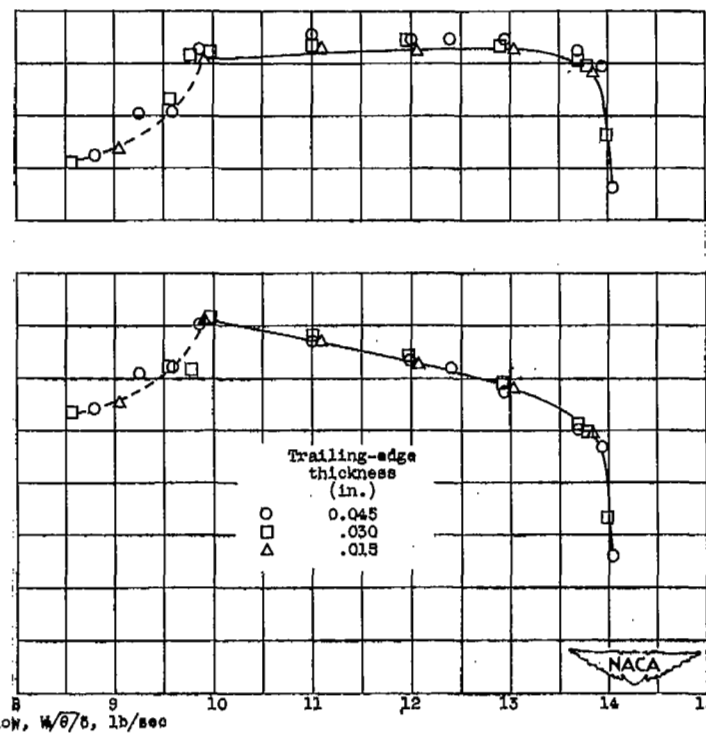


Figure 5. - Variation of total-pressure ratio and adiabatic efficiency with corrected weight flow for three trailing-edge thicknesses.

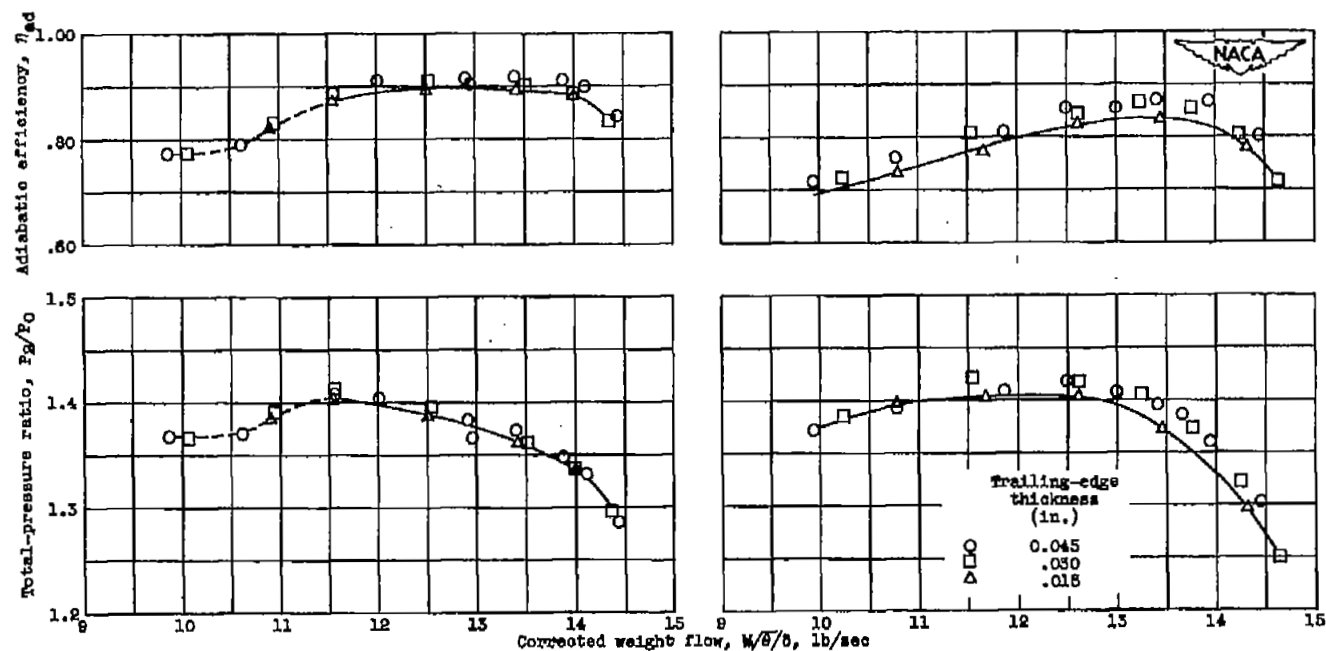


(c) Equivalent tip speed, 736 feet per second.



(d) Equivalent tip speed, 798 feet per second.

Figure 3. - Continued. Variation of total-pressure ratio and adiabatic efficiency with corrected weight flow for three trailing-edge thicknesses.



(a) Equivalent tip speed, 874 feet per second.

(f) Equivalent tip speed, 816 feet per second.

Figure 5. - Concluded. Variation of total-pressure ratio and adiabatic efficiency with corrected weight flow for three trailing-edge thicknesses.

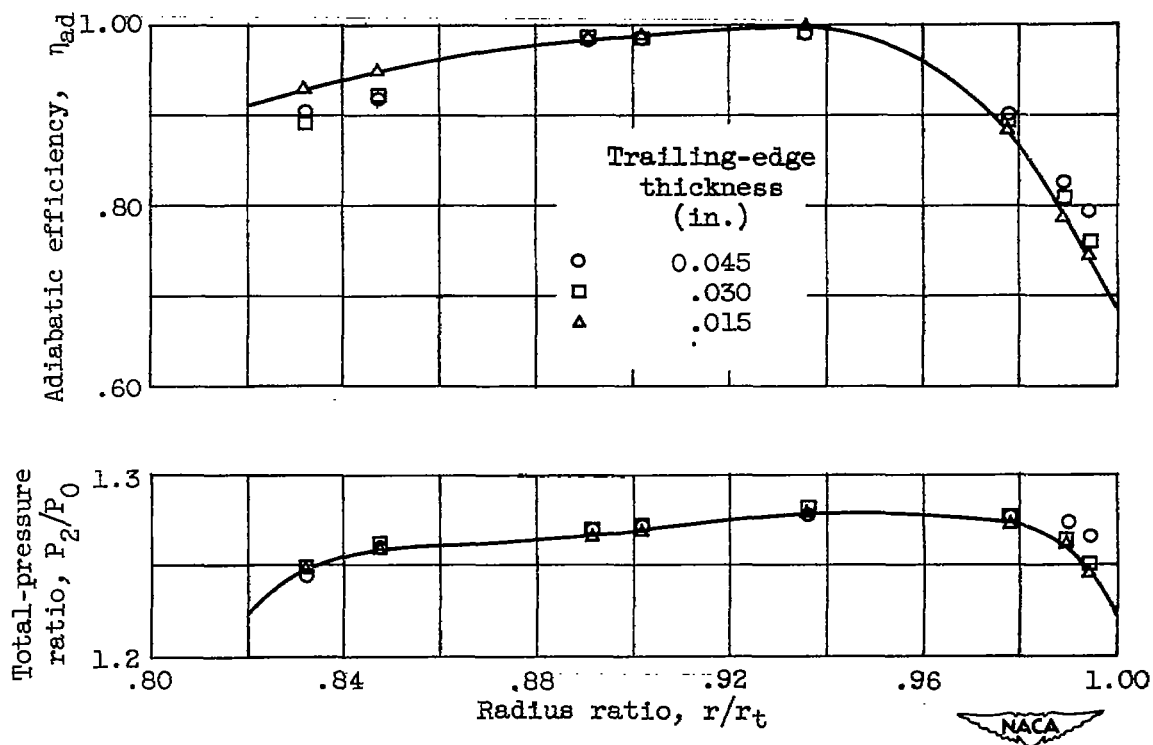


Figure 4. - Radial variation of total-pressure ratio and adiabatic efficiency for three trailing-edge thicknesses at corrected weight flow of 11 pounds per second for equivalent tip speed of 736 feet per second.



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